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# Reduction of moisture problems in old basements

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## ABSTRACT

In Denmark the use of basements is very common especially in older houses. However these basements often suffer from severe moisture problems due to water ingress from the surrounding soil and/or rising damp from the ground. The reason for this is that old basements were made from rather moisture permeable materials and often are of a poor quality. During the years great efforts have been paid to improve the standards of basements especially as they often have changed their function from storage room for coal, old furniture etc. to fitness room, office or even living room. This change calls for more dry basements than before.

The paper describes the measures normally taken to improve the basements i.e. getting it drier including a discussion on whether the part of the basement wall under the ground should be water vapour permeable. Further investigations of new measures to stop rising damp are described including mechanical methods (solid moisture barriers, e.g. stainless steel) as well as chemical methods (moisture barriers applied in fluid form).

## 1. Introduction

In Denmark the use of basements is very common especially in older houses. Originally these basements were used for secondary purposes e.g. for laundry room or storage room for coal, old furniture and other surplus objects.

In the early days a limited amount of basements were used for dwellings in blocks of flats, but as the basements were normally moist this was not good for the health and use of basements for dwellings was consequently soon forbidden (except for already existing dwellings). Today only very few dwellings in basements exist in Denmark and the authorities try to get rid of them whenever they have the opportunity.

The use of basements have changed considerably during the years and today many building owners wish to use the basement for other purposes than originally e.g. as guest room, office, fitness room or even living room. The expectations to the moisture conditions in the basement have therefore increased and many expect today the same conditions in the basement as in the rest of the house.

The paper describes some of the investigations done in order to improve the properties of basements especially in order to avoid problems with moisture. Further is given an overview of commonly used methods for assessing the humidity conditions of basement walls and floors.

### 1.1 Construction types

In Denmark basements were traditionally made with simple constructions.

Floor constructions were directly on the ground, typically made from concrete cast directly against the earth with no capillary breaking layer and no insulation.

Outer walls were made from masonry on a footing either from masonry or poor concrete. These walls were traditionally protected against moisture with fluid bitumen and a screed of mortar but had no insulation. Later concrete walls were used and in many of cases these were cast against earth (formwork was only used on the inside of the wall). Protection of these walls against moisture penetration was not accessible as the outside was not visible. At a later stage normally formwork was used at both sides allowing the outside to be protected against moisture.



Fig. 1. Penetration of water through cracks in a basement wall in periods with heavy rain – cracks were due to bad workmanship. The moist conditions are very unfortunate as the (new) owner uses the room for storage of paper.

It was a prerequisite that basements were only used where the conditions were favourable i.e. on sites with no risk of high groundwater level, as normally no precautions e.g. drain were taken to remove water from the surroundings.

Despite original favourable conditions old basements now often suffer from severe moisture problems. In the worst (very few) cases water penetrates directly through the wall or the floor due to cracks or holes in the constructions, cf. Fig. 1. In the main part moisture problems are due to water ingress from the surrounding soil and/or rising damp from the ground, cf. Fig. 2. The reason for this is that the constructions were made from rather moisture permeable materials and that the protection against moisture was not always sufficient.



Fig. 2. Growth of mould on wall paper on very moist basement walls due to considerable ingress of moisture through the walls and the connection between floor and wall (often very vulnerable).

## 2. Moisture conditions in basements

The moisture conditions in basements are rather complex because there is a big difference in humidity and temperature conditions in the parts above and below ground respectively. The floor construction in a basement functions in the same way as a floor construction directly on the ground and the walls above the ground functions in principle as exterior walls. The walls below the ground are more complex as they are exposed to moisture both from the inside and the outside and besides may be exposed to rising damp. In addition temperature conditions under the ground are different from the conditions above the ground. Normally the temperature in the ground can be expected to be somewhat lower than inside the basement – especially if the basement is heated. The temperature varies over the year but is not in phase with the outside temperature. These conditions are decisive for how and in what direction moisture will be transported.

### 2.1 Reduction of exposure to moisture

The main sources of moisture are normally considered to be water in the soil (including moisture capillary bound in the soil), water vapor from the inside of the basement, rain on the part of the wall, which is above ground and rising damp from the ground water.

The moisture exposure on the outside of the wall includes rainwater penetrating down to the groundwater through the soil, water from defect pipes, sewers etc. and secondary ground water levels due to impermeable soil around the basement. The latter may lead to water pressure on the wall.

In order to ensure acceptable moisture conditions it is necessary to eliminate or at least reduce the exposure on both

### 2.2 Traditional measures to reduce moisture problems

During the years a number of precautions have been prescribed in order to avoid moisture problems, cf. (Brandt et al, 2009).

- Surface water must be directed away from the building, and for that purpose a slope of the terrain of at least 1:40 away from building at the nearest 3 m from the building has been prescribed for many years (50+), cf. (Becher and Korsgaard, 1951 and Andersen, Blach and Christensen, 1974). For buildings in rampant ground a regulation of the terrain must be carried out. If the terrain cannot be regulated sufficiently, a drain must be established at the transition between natural and regulated terrain.
- Drainage around the entire building in order to remove water from the walls and the floor. The drain must be placed 300 mm below the basement floor to ensure proper protection.
- A watertight surface of the basement is prescribed to avoid water from penetrating into the wall. This was traditionally bitumen applied in fluid form and protected with a mortar screed on the outside. In recent years the traditional method has been replaced by a protection with a prefabricated stiff membrane made from plastic combined with a drain around the entire building. The membrane has a corrugated surface creating an air gap between wall and soil. The idea with this is to ensure that if water penetrates behind the membrane it will be immediately removed by the drain i.e. no water pressure can act on the outer surface of the wall.
- A capillary breaking layer is used underneath the floor in order to avoid rising damp in the floor.
- Moisture problems on the inside are primarily connected with mould, dry rot and fungus attacks. These can be avoided by maintaining the RH on a level below 75 %. Traditionally this has been achieved by ventilation of the basement. However, experience show that problems occur in older basements especially when boilers are replaced by district heating and/or the floor construction between basement and dwelling is insulated. Replacement of the boiler means that there is no longer a heat source in the basement (unless a heater is installed) and insulation means that transfer of heat from the floor above is restricted. Both leads to a decrease in the temperature in the basement. As the absolute moisture content in the air remains the same the RH increases when the temperature decreases which might cause favourable conditions for growth of mould and fungi.

## 3. Moisture transport in basement walls

Earlier the strategy for avoiding water penetration was as mentioned above to make a watertight layer on the outer surface of the wall. This means that any moisture in the wall e.g. due to rising damp, could only be removed by evaporation to the inside.

However, looking at the temperature and moisture conditions on the inside and the outside of a basement wall reveal that there is a potential for drying out moisture by diffusion to the outside, cf. Fig. 3.



In wet concrete and soil the relative humidity is 100 %. As the temperature in an old basement wall (concrete or masonry) is higher than in the surrounding soil the water vapour pressure is higher in the wall than in the surrounding soil. Moisture from the wall can consequently evaporate slowly from the wall. If for example it is anticipated that the temperature in the basement wall is 20 °C and the temperature in the soil is 15 °C it can be seen from Fig. 3 that there is an equilibrium between soil at 15 °C and 100 % RH and concrete at 20 °C and 73 % RH. This moisture level is below the level necessary for growth of fungi or mould.

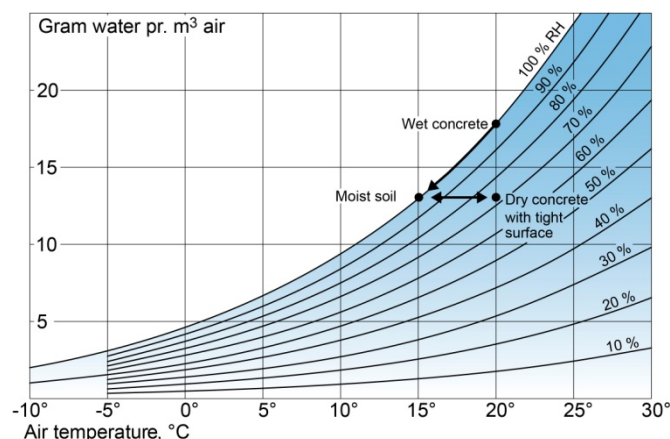


Fig. 3. In wet concrete and soil the relative humidity is 100 %. As the temperature in an old basement wall (concrete or masonry) is higher than in the surrounding soil, the water vapour pressure is higher in the wall than in the surrounding soil. The arrow along the 100 % line shows the direction of diffusion from wet concrete to moist soil (presupposed that the concrete is 20 °C and the temperature of the soil is 15 °C). From the horizontal arrows it can be seen that soil at 15 °C and 100 % RH is in equilibrium with concrete at 20 °C and 73 % RH.

Similar conditions are found for the basement floor.

In order to benefit from this evaporation to the outside it is a prerequisite that there are no vapour tight layers on the outside of the wall. Insulation will enhance the outward vapour transport provided that the insulation is open to diffusion.

In Denmark today it is a requirement that basement constructions (exterior walls and floors) have a relatively low U-value. The recommended way of achieving this is to apply the thermal insulation on the outside of the wall. Suitable types of thermal insulation that are not vapour tight e.g. mineral wool or loose expanded clay pebbles.

In case the ground water raises e.g. due to heavy rain the wall still need to be sufficiently watertight to resist at least shorter periods with a small head of water acting on the outside without allowing (large) quantities of water to penetrate through the wall.

#### 4. Avoidance of rising damp – investigation of mechanical methods

Especially in basements with walls of masonry made with lime mortar there is a considerable risk of rising damp but also in walls made with masonry with other types of mortar or even from weak concrete there is a risk. In some cases the rising damp might cause deterioration of wooden beams in

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the floor construction between basement and the dwelling above. Even in less severe cases the damp might lead to growth of mould on the surfaces.

For the past 20+ years mechanical moisture barriers have been used especially corrugated steel plates vibrated into the joints in the masonry, cf. Fig. 4. However, this method is dependent on a through joint in the wall. Besides it is necessary to make rather large excavations around the building as the machine used to install the plates requires a lot of space. Finally the method often results in damages on walls and surrounding building elements.

A different method has been described by (Møller and Olsen 2011), where five courses of bricks were removed and replaced by a membrane of plastic foil, concrete, damp proof course and hard burnt bricks. A safe but expensive solution.

To overcome the problems with known methods investigations have been undertaken by the GI (The landowners investment association) to find other, new methods also usable without a through joint or even in concrete.



Fig. 4. Installation by vibration of a corrugated steel plate in a through joint in a masonry wall. The machinery is large and demands a lot of space in front of the wall. If the basement floor is removed it is an advantage to install from the inside.

The investigations have been full scale and were focusing on the possibilities of making through joints in the walls. They comprised the use of:

- a giant circular saw with 1.2 m diameter and diamond tipped teeth, cf. Fig. 5. The saw makes a fine but unfortunately narrow joint. Too narrow to allow for introducing a steel plate in the joint. Besides it difficult to handle on the building site.
- a large chain saw with diamond tipped teeth, cf. Fig. 6. The chain saw comes in different types and with different chain width. The joint can thus be made according to the actual requirements as regards how plane and uniform the joint must be. A number of robots have been developed to carry out and control the cutting. Mounting and use of the saw is easy and the full scale tests have shown that the working environment is better than working with the circular saw.
- a wire saw. The wire saw is especially suited where it is difficult to get sufficient space for other methods. All that is needed is two holes to put the wire through, even though it must be possible to access the wall from both sides. The wiresaw does not have the same demand for space in front of the basement as the other methods.

- a jet of water, cf. Fig. 7.



Fig. 5. Circular saw with 1.2 m diameter and diamond tipped teeth. Large excavations around the basement are needed and this together with safety precautions makes the method less desirable.



Fig. 6. Large chain saw with diamond tipped teeth. Found to be the best option for making through joints in basement walls.



Fig. 7. Water-jet for cutting joints in walls. Cutting is possible especially in interior walls of moderate thickness. However, it is difficult/not possible to make a linear cut.

All the tested methods proved usable. However, based on experience from the full scale tests not all were considered suited for commercial use either because the safety

Proceedings of the 5th IBPC, Kyoto, Japan, May 28-31, 2012 precautions were considerable or because they were very expensive in use. For the circular saw for example large excavations around the buildings were required to ensure sufficient space for the equipment. The use of the jet of water was tested only in inner walls. The experience from the tests were that the joint cut with the water-jet was not as linear as the joints achieved with the other methods.

For all methods the work has to be done in stages e.g. roughly 1 m at a time depending on what has been documented by calculations on the actual building.

After making a sufficient joint, 10-20 mm by any of the methods, a suitable moisture barrier, e.g. stainless steel is introduced into the joint. Afterwards the joint is filled with expanding, rapid hardening mortar in order to ensure that the joint is well filled and that the work can continue as fast as possible.

The best suited method for making through joints was found to be the chain saw which is now commercially available in Denmark.

## 5. Avoidance of rising damp – chemical methods

Also the performance of chemical injection methods have been investigated in the project financed by GI (The landowners investment association).

The tests were performed as full scale tests on ten brick walls built in the lab on Danish Technological Institute. Each wall was placed in a container which was water filled in the bottom in order to simulate rising damp.

The injections to the test brick walls were performed by the suppliers of the chemical agents according to their own manuals.

In the test programme 6 different measurement systems were used for documentation of the moisture content and distribution in the masonry.

The results of the tests were that the injection agents had no stopping effect – but may have a reducing/braking effect. No significant decline in moisture level above the injection zone was observed by any of the tested products/systems.

As result of the tests it was shown that the amount of water rising in masonry with cement mortar is much less than in masonry with lime mortar. The distribution of water between bricks and masonry are very different too.

Further information about results of tests with chemical injection methods is found in (Graversen 2007 and Hansen and Frambøll 2008).

## 6. Avoidance of rising damp – additional methods

Other methods for elimination of moisture problems have been suggested. These include:

- *Electrochemical method.* In this method electrical wires are placed in the walls in the basement. The electrical field in the walls is supposed to oppose moisture transport up in the wall. The method has proved to work under small scale laboratory conditions with high water content and to move salts (Ottosen and Röhrig-Dalsgaard 2009), but has not been documented to work under full scale conditions.



- *Impulse resonance.* In this method the electrostatic field in the wall is under influence of electrical impulses. The method is commercially available in Denmark. One project is currently under investigation by one of the authors of this paper. So far no effect of the method has been seen after 2 years surveillance – including measurements with the weighing/drying/weighing method and HF sensor measurements.

## 7. Methods for diagnosing moisture problems

Moisture problems in basements are often seen with the naked eye as moisture stains, discolouration, spalling of mortar or mould growth on interior surfaces. So in many cases no measurements are needed.

If further knowledge of the moisture content in the constructions are required the following methods are recommended:

- *Weighing/drying/weighing:* This method is a reference for all other measurements. The best results are obtaining by cutting the test specimens. If the specimens are drilled there is a loss of approximately 1 weight-% due to the drilling.
- *Nuclear moisture density gauge (Troxler):* This method is based on scattering of neutrons from a radioactive source and may be used between 4-25 weight-% water. This method is independent on any salts in the environment.
- *Microwave moisture measurements (HF-sensor):* These measurements are based on the dielectric properties of water. The dielectric constant of water is 10-20 times higher than of most building materials. This means that when microwaves are emitted, molecules will vibrate, but the energy loss when hitting water molecules will be significant, and the reduced strength of the reflected microwaves expresses the moisture content. This method is independent on salt in the environment. The measuring range is 0-20+ weight-% water.
- *Gypsum blocks:* This method is only useful for masonry normally considered very humid. The method is described in (NORDTEST 2001). The measuring range is 2-20 weight-% water. It requires a long time to obtain equilibrium.
- *Wooden dowels:* This method is only useful for masonry normally considered very dry. The method is described in (NORDTEST 1993). The measuring range is 0-1 weight-% water. It requires a long time to obtain equilibrium.
- *RH measurements with dataloggers:* The dataloggers are placed in contact with the construction and protected from the environment. The measuring range is 0-1 weight-% water. It requires a long time to obtain equilibrium. The method is not very precise.

In Fig. 8 is shown the relationship between relative humidity, water content in weight-% and the saturation degree in the masonry. The Fig. also shows the use of methods for different measuring ranges.

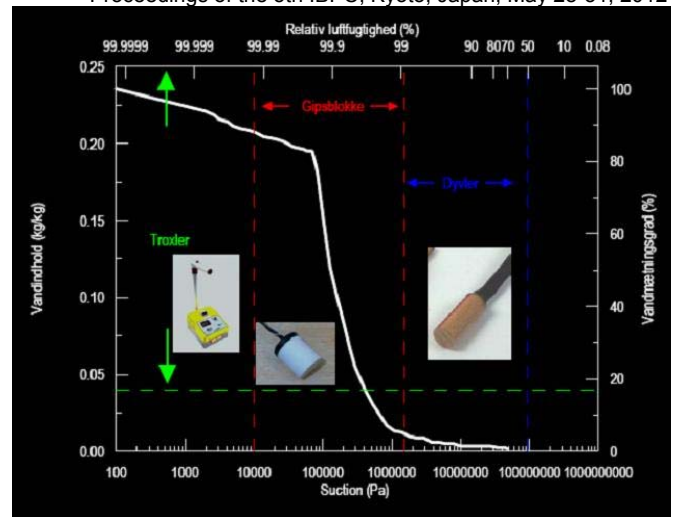


Fig. 8. The diagram shows the relationship between relative humidity, water content in weight-% and the saturation degree in the masonry. Further some of the measuring ranges for some of the recommended instruments/methods are illustrated. It can be seen that with wooden dowels the water content in the range 0.00-0.01 (i.e. 0-1 weight-%) can be measured. With gypsum blocks measurements can be done in the range 0.01-0.20 (1-20 % weight-%) and for the Troxler the range is 0.04-0.25 (4-25 weight-%).

None of the above methods are capable of an absolute measurement in mortar or concrete but they are suited for getting an overview of the distribution of moisture in the construction, cf. Fig. 9, and thus may be of help to find the source(s) for the moisture problems.

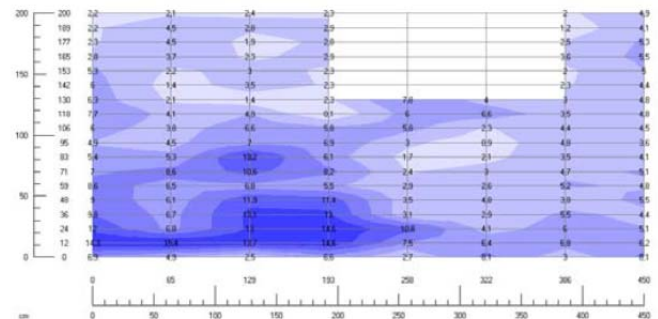


Fig. 9. Distribution of moisture in a basement wall. The darker the colour the higher is the moisture content.

Note that instruments based on measurement of capacitance is only suited for measurements of moisture in the surface and that measurements are influenced by salt in the construction. They are therefore less suited for old masonry drabbed by salt content from the soil, de-icing salt etc.

## 8. Discussion and conclusion

With the results of the investigations performed over the past years it is possible to renovate most basements to at least an acceptable level of humidity. However it is important to note that an old basement will never be as dry as new one where all necessary measures have been taken from the beginning.

For many basements it is neither necessary nor economically feasible to use all the possibilities at hand. In the majority of cases good results may be achieved by the most simple and relatively cheap improvements. The more expensive improvements like introduction of a mechanical moisture

barrier will normally only be used in severe cases and/or in blocks of flats where the cost can be shared by many persons.

The methods to get a drier and more useable basement includes the following:

1. Repairing of all defect constructions and installations – to eliminate exposure to water
2. Regulation of terrain to ensure that water is directed away from the building
3. Heating and/or dehumidification – in order to keep the RH at a level not supporting mould growth etc.
4. Ventilation – to remove moist air from the interior
5. Drain around the building – to reduce the water around the building and eliminate the possibility for a head of water acting on the walls. The drain shall always include a drain along the basement wall to ensure that water rapidly is removed from the basement wall without creating a head of water
6. Exterior thermal insulation of the basement wall – to increase the temperature and thereby also increasing the evaporation from the wall. If it is desired to benefit from diffusion to the outside a thermal insulation with high vapour permeability must be used e.g. mineral wool.
7. Mechanically installed moisture barrier e.g. stainless steel
8. Chemically injection and other methods preferably with documentation and proven record for functioning in practice

No. 4 and 5 above can with very little effort be combined and, and one should not be performed without the other.

It should be mentioned that moisture problem occasionally can occur due to water coming from the floor gully when heavy rain cannot be removed fast enough by the sewer system. To avoid that sort of problem a suitable lock must be installed in connection with the floor gully.

### Acknowledgements

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